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## Forum

# Sleep Loss Gives Rise to Intrusive Thoughts

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**We propose a framework in which top-down inhibitory control networks are impaired by sleep deprivation, giving rise to intrusive thoughts and, consequently, emotion dysregulation. This process leads to a vicious cycle of sleeplessness, persistent unwanted thoughts, and heightened anxiety, ultimately increasing the risk of mental illness.**

## The Benefits of Memory Suppression

Intrusive thoughts occur when everyday encounters trigger the retrieval of unpleasant past experiences. One way that people control intrusive thoughts is by directly suppressing them, thereby relieving consciousness of unwanted memories. Beyond this initial respite, memory suppression has far-reaching benefits. Specifically, suppressing an unwanted thought weakens the corresponding memory trace, reducing the likelihood of recurrent thought intrusions [1]. Moreover, memory suppression alleviates the affective charge associated with unpleasant past experiences, dampening the emotional intensity of aversive memories [2]. These lasting benefits of memory suppression are believed to be integral to healthy emotion regulation [3].

Memory suppression is orchestrated by the right dorsolateral prefrontal cortex (rDLPFC), which, via top-down inhibitory mechanisms, downregulates retrieval-related activity in hippocampus and arousal responses in amygdala [2]. We propose a framework in which the inhibitory control network underpinning memory suppression is

impaired by sleep loss. This impairment allows intrusive thoughts to break into consciousness unabated, undermining the benefits of memory suppression for emotion regulation. We argue that deficient memory control plays an important role in the well-established relationship between sleep disturbance and anxiety disorder.

## Sleep Loss Impairs Memory Control

Central to our framework is that sleep loss diminishes people's ability to suppress unwanted thoughts by impairing top-down inhibitory projections from rDLPFC to hippocampus and amygdala. There are several lines of evidence to support this idea. The rDLPFC is a domain-general executive control region that is recruited to suppress motor responses as well as unwanted thoughts [4]. Sleep deprivation leads to reduced rDLPFC activation during motor response inhibition, resulting in poorer inhibitory control [5]. Correspondingly, suppressing unwanted thoughts is more difficult under conditions of mental fatigue [6].

Recent work has demonstrated that sleep-deprived individuals are ineffective at suppressing unwanted thoughts [7]. Whereas memory suppression reduces future thought intrusions in well-rested people, sleep-deprived individuals fail to exhibit the same intrusion-reducing benefit of effective memory control. Moreover, even after sleep-deprived individuals gain command of an unwanted thought, they are prone to relapses in memory control, such that the previously suppressed thought re-emerges into conscious awareness. These empirical findings collectively support the mainstay of our framework: sleep deprivation impairs the inhibitory control network underlying memory suppression, allowing unwanted thoughts to prevail over futile suppression attempts and remain intrusive over time.

## Deficient Memory Control Undermines Emotion Regulation

Emotion dysregulation is a robust consequence of insufficient sleep. Another component of our framework is that emotional disturbances following sleep loss arise because of impaired memory control. This idea builds on the view that memory control constitutes a fundamental mechanism of emotion regulation [3]. From this perspective, by evoking retrieval of an unwanted memory, seemingly innocuous stimuli have the power to elicit emotional reactions that mimic the original, traumatic experience. Hence, failure to suppress an unwanted memory when sleep deprived allows both the content and affective tone of that memory (represented by hippocampus and amygdala, respectively [2]) to intrude into consciousness, prompting a deterioration of emotional well-being. Supporting this view, whereas in well-rested people repeatedly suppressing thoughts about unpleasant images reduces subjective and psychophysiological arousal responses to those images, no such salutary benefit of memory suppression is observed in sleep-deprived individuals [7].

Our framework can be extended to exogenously generated emotions, which are also strongly influenced by memory (e.g., aversive responses to snakes are derived from learned expectations about the dangers posed by snakes [3]). Accordingly, failure to effectively downregulate pre-existing representations of fear after sleep loss will lead to hyperarousal when encountering a potential threat. Indeed, sleep deprivation impairs inhibitory connections from prefrontal cortex to amygdala during exposure to aversive video clips, leading to hyperactivity in amygdala and heightened feelings of anxiety [8]. Together, these data support the second key principle of our framework: impaired memory control following sleep loss undermines emotion regulation by allowing the affective charge of unpleasant experiences to endure.

### Insomnia and Anxiety Disorder: A Missing Link?

We argue that the well-known relationship between insomnia and anxiety disorder is underpinned, in part, by impaired memory control. Under our framework, deficiency of the memory suppression network following bouts of insufficient sleep gives

rise to intrusive thoughts and, consequently, emotion dysregulation. Incessant thought intrusions and affective disturbances exacerbate sleep problems, leading to accumulating sleep debt, more persistent and distressing intrusive thoughts, and amplified emotional distress. This vicious cycle (Figure 1)

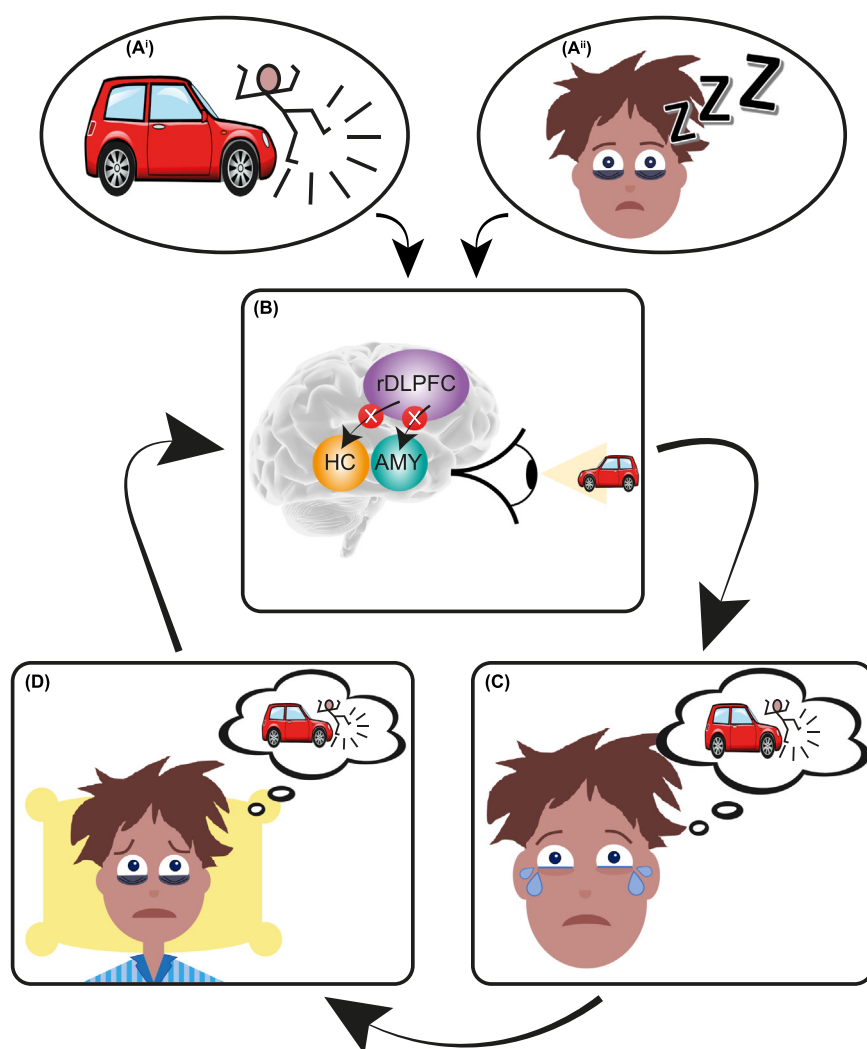
culminates in a chronic and debilitating state of anxiety.

In the weeks and months following a traumatic experience, many individuals will overcome the adversity unscathed. Others, however, will go on to develop post-traumatic stress disorder (PTSD), an anxiety disorder characterized by intrusive and distressing thoughts about the traumatic event. Given the prevalence of chronic sleep disturbances among PTSD sufferers, our framework can offer novel insights into how PTSD may develop in the aftermath of trauma. Specifically, deficiencies in the memory control network following sleep loss impair attempts to quash thoughts about a distressing event, preventing downregulation of the traumatic memory trace and its emotional charge. Failed suppression may also strengthen memories in a manner akin to retrieval practice, rendering them more resilient to future suppression attempts.

Consistent with this view, among survivors of the 2015 Paris terrorist attacks, those who went on to develop PTSD exhibited disruption in memory control networks during attempts to suppress unwanted thoughts [9]. Correspondingly, whereas repeatedly suppressing specific memories weakens those memories in healthy, trauma-exposed individuals, PTSD sufferers fail to achieve the same suppression-induced forgetting benefit [10].

Note that our framework speaks to traumatic memories that are already consolidated. Whether sleep loss in the immediate aftermath of trauma (which might arise from upsetting memories of the traumatic event itself) could help to prevent PTSD by disrupting overnight consolidation is a separate issue.

The self-reinforcing cycle of disturbed sleep, intrusive thoughts, and emotion dysregulation that we have described can also be applied to other psychiatric



**Figure 1. Integrated View of Sleep Loss, Intrusive Thoughts, and Emotion Dysregulation.** (A) A traumatic experience and (A') sleeplessness, which can be viewed as prerequisites for the key principles of our framework. (B) When sleep deprived, upon encountering a reminder of the traumatic experience (red car), the right dorsolateral prefrontal cortex (rDLPFC) fails to downregulate retrieval-related activity in hippocampus (HC) and arousal responses in amygdala (AMY). (C) Impairments to the memory control network prevent sleep-deprived individuals from directly suppressing unwanted thoughts, undermining the opportunity to weaken aversive memory traces and their emotional tone. (D) Intrusive thoughts and affective disturbances obstruct the sleep needed to support recovery. A vicious cycle ensues, giving rise to persistent and distressing thought intrusions, severe emotion dysregulation, and chronic sleeplessness, culminating in mental illness.

### Box 1. Predictions for Future Research

- Does sleep loss impair top-down inhibitory control of brain regions involved in memory retrieval and emotional arousal? Sleep deprivation should weaken inhibitory projections from rDLPFC to hippocampus and amygdala during memory suppression.
- Can the well-known link between sleep loss and emotion dysregulation be attributed to deficient control of aversive memories? The extent to which memory suppression networks are impaired by sleep deprivation should predict the degree of emotional disturbance.
- Do the effects of sleep loss on memory suppression abilities predict resilience to trauma? Individuals who exhibit robust memory control when sleep deprived should be least likely to develop PTSD following exposure to trauma.
- How is thought substitution affected by sleep loss? Sleep-deprived individuals might be able to achieve effective memory control by directing retrieval operations to other, nonaversive memories.

disorders. Specifically, our framework can provide insights into the pathology of major depressive disorder, obsessive-compulsive disorder, and schizophrenia, all of which are characterized by persistent, unwanted thoughts and co-occurring sleep disturbances. Insomnia is nevertheless associated with biological irregularities that strongly impact the response to stress (i.e., dysregulation of the hypothalamic-pituitary-adrenal axis), potentially heightening anxiety risk in a manner that is distinct from the proposed memory control deficits arising from acute sleep deprivation.

### Thought Substitution: A Potential Lifeline

As an alternative to memory suppression, effective memory control can be achieved via thought substitution, which involves redirecting retrieval operations to other, nonaversive memories. The brain mechanisms of thought substitution are distinct from those underpinning memory suppression, relying on a predominantly left-lateralized network centered on the caudal and ventrolateral prefrontal cortex [11]. Given these opposing mechanisms, the consequences of sleep deprivation might be less severe for thought substitution than for memory suppression, although the

efficacy of thought substitution among individuals with psychiatric disorders (for whom sleep disturbances are commonplace) is an open issue at present [12].

### Concluding Remarks

We have outlined a neurocognitive framework to explain how sleep loss gives rise to intrusive thoughts and emotion dysregulation. We propose that sleep deprivation impairs top-down inhibitory control of brain regions involved in memory retrieval and emotional arousal. The consequences of this impairment are twofold. First, unwelcome thoughts are given free rein to dominate awareness. Second, the abiding benefits of memory suppression are bypassed, allowing aversive memories and their emotional tone to endure. This process is self-reinforcing and can contribute to the development of anxiety disorder. Testable predictions for our framework are outlined in Box 1. We expect that impairment of memory control mechanisms will emerge as a key contributor to the link between sleep disturbances and mental illness.

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### Declaration of Interests

No interests are declared.

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